NASA Innovative Advanced Concepts

Dual-mode Propulsion System Enabling CubeSat Exploration of the Solar System

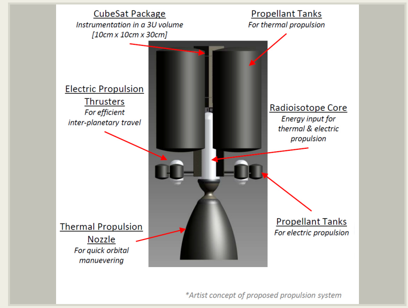
Completed Technology Project (2013 - 2014)

Project Introduction

Researchers at the Center for Space Nuclear Research (CSNR) are proposing a radioisotope-based, dual-mode, low mass propulsion system for a CubeSat payload capable of extending their exploration realm out of LEO. Such an integrated propulsion system would allow for beneficial exploration to be conducted, even within the current budget limitations. With the cost of planetary exploration rising and budgets for such missions declining newer, cheaper, i.e. low mass, systems must be developed to perform exploration. Currently, small scientific beds which perform limited tasks are being developed and launched into Low Earth Orbit (LEO) in the form of small-scale satellite units, i.e. CubeSats, utilizing solar-based power. However, if a reasonable propulsion system could be developed, these low cost CubeSat platforms could be used to perform exploration of various extra-terrestrial bodies within the solar system; such as Europa. Current standard propulsion technology does not provide the complete answer. Chemical-based systems are high mass and provide insufficient performance for deep space missions. Electric propulsion (EP) is very efficient, i.e. high Isp, but has low thrust, leading to long mission times if orbital maneuvering is required. Thermal propulsion (TP) yields high thrust, but at the expense of a high consumption rate of propellant. Therefore, pairing an EP and TP system into a dual-mode propulsion unit becomes beneficial, where the strengths of each system are used appropriately. The high thrusting capabilities of the thermal mode are ideal for quick Earth orbit escape, drastic orbital maneuvering and orbital insertion at location. The high efficiency of the electric-mode is ideal for interplanetary travel. Researchers at the Center for Space Nuclear Research (CSNR) are proposing a radioisotope-based, dual-mode, low mass propulsion system for a CubeSat payload capable of extending their exploration realm out of LEO. Such an integrated propulsion system would allow for beneficial exploration to be conducted, even within the current budget limitations. For the proposed work a complete system design will be provided, optimized for a Europa destination with a 10 kg payload. Modeling software such as AGI STK, COMSOL, MALTO and Aspen will be used to design and optimize the various components of the overall system. The design of an experiment will also be conducted to use existing CSNR hardware to evaluate propellant performance within the thermal mode.

Anticipated Benefits

Researchers at the Center for Space Nuclear Research (CSNR) are proposing a low mass, radioisotope-based, dual-mode propulsion system capable of extending the exploration realm of these CubeSats out of LEO.



Concept Diagram

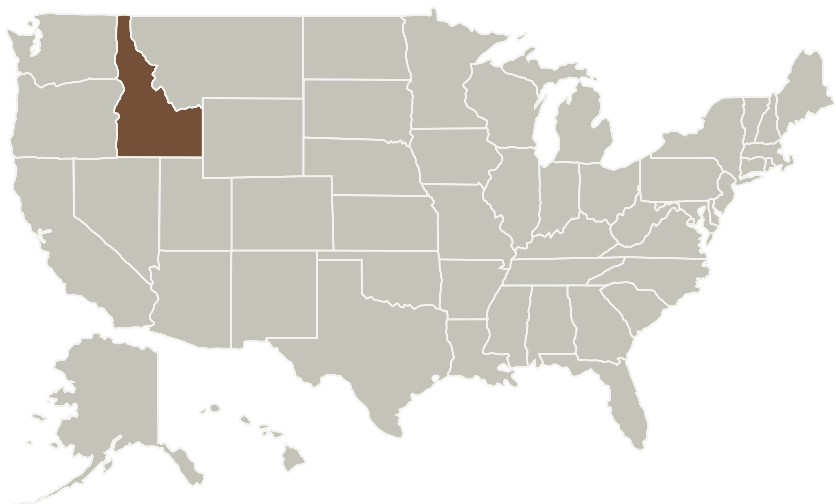
Table of Contents

Project Introduction	1
Anticipated Benefits	1
Primary U.S. Work Locations and Key Partners	2
Project Transitions	2
Organizational Responsibility	2
Project Management	2
Technology Maturity (TRL)	2
Technology Areas	3
Target Destinations	3
Images	4

Dual-mode Propulsion System Enabling CubeSat Exploration of the Solar System

Completed Technology Project (2013 - 2014)

Primary U.S. Work Locations and Key Partners



Organizations Performing Work	Role	Type	Location
Center for Space Nuclear Research	Lead Organization	Industry	
Universities Space Research Association(USRA)	Supporting Organization	R&D Center	Huntsville, Alabama
University of Southern California(USC)	Supporting Organization	Academia	Los Angeles, California

Primary U.S. Work Locations
Idaho

Project Transitions

October 2013: Project Start

Organizational Responsibility

Responsible Mission Directorate:

Space Technology Mission Directorate (STMD)

Lead Organization:

Center for Space Nuclear Research

Responsible Program:

NASA Innovative Advanced Concepts

Project Management

Program Director:

Jason E Derleth

Program Manager:

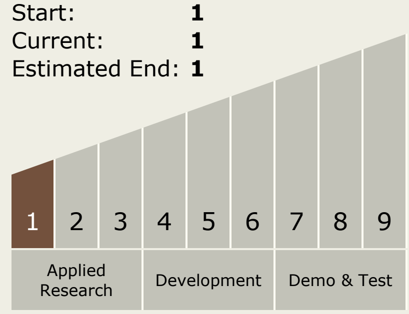
Eric A Eberly

Principal Investigator:

Nathan D Jerred

Technology Maturity (TRL)

Start: **1**
Current: **1**
Estimated End: **1**



Dual-mode Propulsion System Enabling CubeSat Exploration of the Solar System

Completed Technology Project (2013 - 2014)

September 2014: Closed out

Closeout Summary: The primary goal of this study was to flesh out the initial c oncept of a radioisotope-based propulsion system for small payloads. The design of which was performed in the context of delivering a 6U payload to the orbit of Enceladus. Building on the work completed here the system concept will need to be further matured as its design is further optimized. Modeling of the thermal ca pacitor core, using programs such as COMSOL Multiphysics, will need to become more integrated to fully determine the thermal interactions of the various centra l components of the core including the thermal capacitor, insulation layers, supp ort structures, etc and their interactions with one another. Additionally, as desig n changes occur through the evolution of this concept, modeling will need to be used to address those changes as well. Optimization of the core design will need to be continued, progressing to the inclusion of an appropriate containment met hod for a PCM thermal capacitor. Research on silicon will need to be continued a nd experiments will need to be conducted, cycling silicon through its liquid-to-so lid phase change in order to determine potential stresses on the system. Additio nally, methods to alleviate potential stresses and ensuring thermal conductive p athways between a PCM thermal capacitor and flow channels are maintained will need to be further evaluated. Proper understanding and functionality of the ther mal capacitor is key to the development of this concept and Figure 34 shows det ails of the CSNR's remote laser heating apparatus that can be used to better un derstand silicon's phase change process. Follow on work will need to include the use of a CFD code, such as Starr CCM+, to model the thermal hydraulics of the system and to model the exchange of energy between both the thermal capacito r and the absorber heat rejection subsystem with a flowing gas. Ultimately, exp erimentation will need to be conducted demonstrating the heat transfer from a P CM to a flowing gas to demonstrate this key technology of the concept. This can be performed using existing equipment and facilities available to the CSNR. A la boratory-scale test rig used to perform flow experiments through the CSNR's Ma rs Hopper concept is seen in Figure 14 (a). A similar test rig will be constructed f or possible thermal hydraulic experiments, designed specifically for a PCM therm al capacitor. Figure 14 (b) shows the high temperature blowdown facility that is capable of safely housing/conducting the potential thermal hydraulic experiment s. These same facilities can be used to house a sub-scale test article for thermal hydraulic experiments to demonstrate the absorption of energy from a flowing g as within the heat rejection subsystem, which is a key technology to a low mas s, low footprint, integrated conversion subsystem. Experimental data will aid in validating CFD modeling, which in turn will lead to better refinement of the vario us flow loops of the system and a better understanding of a fully integrated syst em. Utilizing existing CSNR facilities to conduct experimental work and to demo nstrate the thermal hydraulics of the system allows for more results to be achiev ed in future studies. power requirement of the system is continually met; resulti ng in the design of a fully integrated conversion system. Additionally, a better as sessment of the Brayton engine's turbo-machinery components will need to be c onducted. Ultimately, data gathered through thermal hydraulic experiments and CFD modeling will allow for a better prediction of the expected turbine inlet and outlet temperatures; aiding in the turbo-machinery assessment. The overall mis sion architecture of an Enceladus orbiter mission will need to be further refined. In future studies the instrumentation system will continue to evolve and the inte gration of each instrument in to the propulsion system will need to be complete d. An assessment of a larger payload can prove to be beneficial, given the adde d mass is acceptable. The trajectory phases of the mission will need to be furthe r developed and optimized. Specifically, the periapsis pumping phasing maneuve

Technology Areas

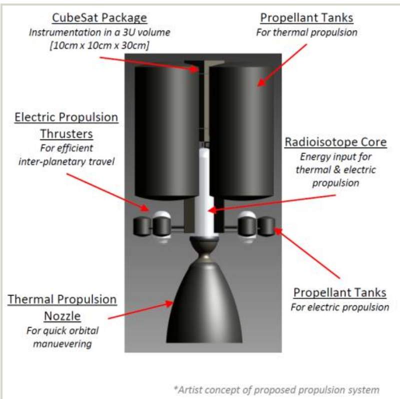
Primary:

- TX01 Propulsion Systems
  └ TX01.2 Electric Space Propulsion
    └ TX01.2.2 Electrostatic

Target Destinations

The Moon, Mars, Others Inside the Solar System

Images



Dual-mode Propulsion System Enabling CubeSat Exploration of the Solar System
Concept Diagram
(https://techport.nasa.gov/image/102251)